STAFF SUMMARY SHEET

	TO	ACTION	SIGNATURE (*Surname*), GRADE AND DATE		TO	ACTION	SIGNATURE (*Surname*), GRADE AND DATE
1	DFCE	sig	Col 13 Apr 12 (Department Head or Designee)	6			
2	DFER	approve	Brent A Rocher, Col 13 Apr 2012	7			
3	DFx	action	Dr. Stanley P. Rader	8			
4				9			
5				10			

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SUMMARY

1. PURPOSE. To provide security and policy review on the document at Tab 1 prior to release to the public.

2. BACKGROUND.
Authors: C1C Casey Haubluetzel and Dr. Stanley P. Rader

Title: Resilience in the Context of a Stormwater Infrastructure Report Card

Circle one: Abstract Tech Report Journal Article Speech Paper Presentation Poster

Check all that apply (For Communications Purposes):

[] CRADA (Cooperative Research and Development Agreement) exists

[] Photo/ Video Opportunities [] STEM-outreach Related [] New Invention/ Discovery/ Patent

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3. DISCUSSION. This paper is the result of a two-semester independent study effort by C1C Habluetzel. It discusses physical infrastructure resilience as it relates to stormwater infrastructure systems. Specifically, it applies the resilience discussion to the Colorado Springs stormwater system using the American Society of Civil Engineers local infrastructure report card as the vehicle.

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RESILIENCE IN THE CONTEXT OF A STORMWATER INFRASTRUCTURE REPORT CARD

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ABSTRACT

This article is a product of an independent study effort accomplished over the span of two semesters at the United States Air Force Academy. The author and advisor set out with the intent of investigating the state of current thought regarding resiliency as it applies to domestic public infrastructure systems. In order to bridge the gap between theory and practice, an American Society of Civil Engineers local Infrastructure Report Card is used as a case study vehicle. The intent of this approach is to provide a real life community service while at the same time to gain a better understanding of how infrastructure resiliency principals are applied at a practical, local level.

KEY WORDS

Resilience, Infrastructure, Report Card, Stormwater.

OVERVIEW

The United States is engaged in asymmetric conflicts around the globe and leading the international effort to defeat terrorism and protect democratic societies. While overseas campaigns to engage the terrorists on their home turf have garnered most of the public attention over the last decade, parallel efforts to protect our citizens at home have also been waged during this time. Most citizens have personally experienced the results of this domestic campaign in the course of routine air travel or visits to government buildings since the September 2001 attacks. A less obvious aspect of protecting the U.S. citizenry is providing protection for the nation's physical infrastructure. America's civil engineers are front and center in the effort to assess critical infrastructure vulnerabilities and develop strategies for strengthening this often-ignored but undoubtedly crucial component of the national quality of life.

In addition to the terrorist threats to domestic infrastructure alluded to above, the civil engineer must consider threats due to natural hazards when evaluating physical infrastructure systems. While the cause and source of potential destruction may be quite different between terrorism and natural disasters, both must be considered and countered in order to achieve the goal of truly

robust public infrastructure systems. Regardless of threat, a key measure of infrastructure quality is resiliency.

In the realm of material science and structural engineering, resiliency is defined as the physical property of a material that enables it to return to its original shape or position after dislocation or deformation. When applied to a community's physical infrastructure, resilience is the ability to anticipate, survive, and recover from external disruptions, such as terrorist attacks or human-caused accidents, or from natural disasters, such as tsunamis, earthquakes, hurricanes, tornados, wild fires, blizzards, or flooding. The American Society of Civil Engineers (ASCE) template for grading infrastructure systems includes seven fundamental components for evaluation, the last of which is resilience. This paper addresses the specific topic of physical infrastructure resilience. The discussion takes place in the context of an ASCE Infrastructure Report Card initiative. Specifically, the Colorado Springs Area local infrastructure report card is used as a conduit to discuss resiliency as it applies to Colorado Springs's storm water system. Overarching resiliency principles are discussed and applied to the stormwater system with the intent of contributing to the national resiliency conversation, providing a resource for future regional infrastructure report card efforts, and helping the Colorado Springs community to understand and improve local stormwater infrastructure resilience.

BACKGROUND

The Air Force Academy Department of Civil and Environmental Engineering faculty recognizes the importance of providing its graduates with an understanding of physical infrastructure fundamentals and preparing them for leadership in protecting Air Force critical assets (1). In the continuing process of defining and refining the Department's infrastructure protection curriculum, the author and advisor decided to leverage the author's academic research via application of this research to a local ASCE Infrastructure Report Card initiative. ASCE's current guide for state and regional report cards lists seven fundamental components to use when evaluating public infrastructure systems. They are capacity, condition, funding, future need, operation and maintenance, public safety and resilience (2). Of these, resilience was chosen as the specific area for focus due to its current emphasis in the infrastructure protection community and immediate relevance to Air Force critical infrastructure protection concerns.

The Air Force Academy emphasizes community service as an important component of a cadet's character development. This, along with the imperative of infrastructure protection education, as well as the advisor's responsibilities as chairman of the local infrastructure report card initiative, provided a fortuitous synergism to achieve important objectives in each of these three arenas.

The ASCE Southern Colorado Branch Board of Directors voted to sponsor development of a local Infrastructure Report Card in July of 2011. Tough economic times over the previous three years and associated decreases in both tax revenues and staffing have placed a strain on the ability of local jurisdictions in the Pikes Peak region to maintain and/or improve public infrastructure systems. The Board of Directors felt that producing a local Infrastructure Report Card would provide a significant public service by helping to educate the community regarding both the importance and the vulnerabilities of their local infrastructure systems. The original

intent of the Board was to accomplish an infrastructure assessment of all of El Paso County, which is the most populous county in Colorado, covering over 2,100 square miles. However, the number of jurisdictions and sheer magnitude of the infrastructure systems covering El Paso County made it impossible for the relatively few Southern Colorado Branch Report Card volunteers to evaluate the entire county. Consequently, the Report Card scope was reduced to the greater Colorado Springs area, which still encompasses approximately 195 square miles within the city limits and is home to about 430,000 people, not including adjacent communities.

The 2009 national report card published by ASCE evaluated fifteen separate infrastructure categories: aviation, bridges, dams, drinking water, energy, hazardous waste, inland waterways, levees, public parks and recreation, rail, roads schools, solid waste, transit and wastewater (3). Of necessity, the Colorado Springs infrastructure report card evaluates five of the fifteen categories, and adds an additional infrastructure category not included in the national report card. The five national categories also evaluated in the Colorado Springs report card include bridges, drinking water, roads, transit and wastewater. Stormwater was added to the local report card due to its significant impact on other local infrastructure systems as well as real property and life safety. So, in addition to completing an evaluation of the Colorado Springs stormwater system, the report card stormwater subcommittee developed a template for stormwater system evaluation that can potentially be of use nation-wide.

LITERATURE SEARCH

The author began his individual study effort on resiliency analysis in the fall of 2011 with a partial review of the existing literature. Infrastructure resiliency is a current topic of interest domestically in both the public and private sectors; therefore the amount of literature available is extensive. Due to the considerable amount of resiliency information available, the literature search focused on infrastructure resiliency at the national level, with the intent of applying knowledge gained to the local ASCE Infrastructure Report Card effort.

Given ASCE's emphasis on infrastructure health since it released its first national infrastructure report card in 1998, it was natural to turn to that organization first for information on infrastructure resiliency. A broad understanding of infrastructure categories, infrastructure research and grading processes and infrastructure resilience characteristics was obtained via review of various ASCE articles.

In addition to the ASCE resources, other articles were reviewed that dealt with infrastructure resiliency (4)(5)(6). Resiliency principals and descriptions of the application of these principals to specific infrastructure sectors, as communicated in the articles, served as guides for how to address local infrastructure system resilience issues.

INFRASTRUCTURE RESILIENCE

Resilience is one of the key indicators an infrastructure system's quality. Although resilience has multiple definitions depending on context, infrastructure resilience refers to the capability of a system to prevent or protect against significant multi-hazard threats and its ability to rapidly recover and ensure continuity of critical services, with minimal negative impact to the public health and safety, following a catastrophic event (7). ASCE's position is that building resilience into infrastructure systems must be required to protect the natural environment and withstand both natural and man-made disasters. We must ensure that all users of infrastructure are safe and that future generations will also be able to enjoy the infrastructure we rely on today (8). The ASCE approach to measuring an infrastructure system's resilience is to evaluate the system with respect to four key qualities: *robustness, redundancy, resourcefulness* and *rapidity.*

For an infrastructure system to exhibit resilience, it must be strong enough to endure an elevated level of stress. This is called *robustness.* When catastrophic events such as an earthquake or terrorist attack occur, an infrastructure system that is robust will be able to continue its original function without failure. This does not necessarily imply that the system won't experience decreased performance for a period of time, but does infer that the system can continue operating at some minimum level of performance. The minimum acceptable level of performance should be a consideration in both the design and assessment of infrastructure systems.

The second key indicator of an infrastructure system's resiliency is its *redundancy.* If part or all of the system is destroyed or disabled, there must be alternate means of providing some continuing minimum level of that system's service. The closer the alternate service level is to the original service level, the greater is the system's redundancy. A typical approach to increasing a system's redundancy is to provide relatively low cost back-up assets which are designed to operate on a temporary basis while the primary infrastructure system is being restored.

When critical infrastructure systems are damaged or destroyed, the quality of the response has a significant impact on the system's resilience. What level of resources are available, and how effectively can they be marshaled and committed to repair or replace the affected system? The ability to commit the right resources in the correct manner in response to a catastrophic event defines the system's *resourcefulness.* Flexibility in problem solving and decision making by officials responsible for the infrastructure system, as well as planning for and a willingness to share resources across jurisdictional and organizational boundaries are key components to obtaining and maintaining a resourceful infrastructure system.

The final key indicator of infrastructure resilience is *rapidity.* Rapidity is an infrastructure system's ability to recover quickly from damage or failure. Rapidity depends on effective preplanning, availability of manpower, materials and equipment, efficient communications, and timely decision-making. It is closely related to the system's resourcefulness, as discussed above. The severity of the event and extent of the resulting damage obviously have a major impact on how quickly an infrastructure system can be restored. While potential event severity is certainly to be considered when designing an infrastructure system, the magnitude of an actual catastrophic event is normally beyond the control of those responsible for the infrastructure

system. Therefore, rapidity is a relative metric and must be scaled according to the magnitude of the damage to the system.

It should be obvious that as a general rule, improving the robustness, redundancy, resourcefulness and/or rapidity of an infrastructure system, thus increasing its resilience, requires money. While "working smarter" certainly has a place in increasing infrastructure resilience, there can be no denying that most of the means of increasing resilience require applications of additional labor and/or materials. As with most things in life, whether formal or informal, it comes down to a cost/benefit analysis. Where is the tipping point between what is reasonable and what is excessive when allocating finite resources to infrastructure improvement? Addressing that challenging question is well beyond the scope of this article.

The focus of this discussion is on infrastructure resilience. But as previously noted, resilience is but one of seven fundamental components used to evaluate infrastructure using ASCE's report card grading process. There are definite dependencies and interrelationships between resilience and the other six fundamental components; capacity, condition, funding, future need, operations and maintenance, and public safety. These interdependencies are not discussed here, but the broader context should be kept in mind when considering infrastructure resilience.

As was noted, the Colorado Springs report card initiative addresses only five of the fifteen infrastructure categories evaluated in ASCE's national report card, and adds one additional category. The infrastructure categories considered locally (bridges, drinking water, roads, transit, wastewater and stormwater) do not exist in a vacuum. Without too much effort, one can see how each of these six infrastructure systems can and does impact each of the other five systems. This observation can be expanded to apply to basically all of the other systems not addressed in the Colorado Springs report card (aviation, dams, energy, hazardous waste, inland waterways, levees, public parks and recreation, rail, schools, and solid waste). The subsequent discussion regarding the stormwater infrastructure is not intended to imply that this is a stovepiped system. Rather, interrelationships between the stormwater and other systems are omitted for the sake of brevity. Others have recognized the complex challenges spawned by these interdependencies and advocated for overarching, holistic strategies for increasing infrastructure resiliency in an increasingly interdependent environment (9).

STORMWATER AND THE INFRASTRUCTURE REPORT CARD

While the 2009 Report Card for America's Infrastructure did evaluate dams, inland waterways and levees, it did not include a "stormwater" category. The Colorado Springs Area report card committee decided to include stormwater as a separate category due to its impact on other infrastructure systems as well as general impact on the local community's quality of life and safety. The Colorado Springs Area committee was not the first or only report card committee in the nation to add stormwater as a separate category. The 2004 San Diego County, 2007 Wisconsin, and 2011 Maryland report card committees are among those that assessed stormwater systems. However, Colorado Springs's stormwater subcommittee did break some new ground developing a stormwater system evaluation template from scratch. Their objective was to not

only serve the local community through their efforts, but also contribute nationally by offering their template for use by others around the country.

Figure 1. Cottonwood Creek in eastern Colorado Springs
Courtesy City of Colorado Springs

A RESILIENT STORMWATER SYSTEM?

Although Colorado Springs is located in a semi-arid region, with an average annual rainfall of around 17 inches and average total annual snowfall of approximately 42 inches, stormwater management is a significant concern. The summer months present the greatest challenge, featuring violent thunder storms which can cause significant property damage and threaten citizens' lives. As a result, the existing Colorado Springs area stormwater system is extensive.

The stormwater infrastructure system has approximately 20,230 storm point features such as buried manholes and inlets, 566 miles of buried storm pipe, 250 miles of open drainage features, and 3,500 discharge points that drain into those open drainage features. The municipal city limits boundary alone accounts for 195 square miles of drainage area that must be effectively drained

by the stormwater infrastructure system in order to safely divert stormwater from structures and roads. Unlike sanitary sewage, stormwater is not treated, so that aquatic life can be harmed if pollutants get into the stormwater system. In addition, other downstream potable water systems use surface waters discharged from the Colorado Springs stormwater system for consumable use. So not only must the system protect life and property during a storm event, it should also protect the water quality of the system's discharges.

How robust is Colorado Springs's stormwater infrastructure system? Can it be subjected to an elevated stormwater demand and continue to operate effectively? The answer is somewhat of a mixed bag. The National Center for Atmospheric Research lists the 22 most damaging floods in recorded Colorado history, of which only two were in Colorado Springs (10). The 1935 Monument Creek flood killed 18 people, but occurred prior to construction of most of the current stormwater infrastructure system. The April 1999 flood, however, caused an estimated $15 million of damage in Colorado Springs, washing out bridges and roads, causing severe erosion, flooding homes and businesses, backing up sewers, and breaking a major sewer line. Not only did the stormwater system fail to protect bridges, roads and buildings, it also allowed more than 60 million gallons of untreated wastewater to pour into Fountain Creek, the primary drainage way flowing south out of the city. The one positive result from the flood is that there were no fatalities.

Figure 2. Platte Avenue over Sand Creek, Colorado Springs, 2009
Courtesy City of Colorado Springs

An additional indicator of the stormwater infrastructure robustness was highlighted by the ASCE Report Card stormwater team. By reviewing six selected drainageways within the City, the committee found that approximately 1,700 habitable structures lie within the 100-year floodplain. Many of these structures are at risk for events as frequent as the 10-year flood. FEMA data from 1978 to 2010 shows that Colorado Springs had the largest number of claims filed of any municipality in Colorado despite the fact that the City did not experience a flood event in excess of a 25-year recurrence interval during that period. To summarize, the stormwater system performs adequately under normal to somewhat elevated flows, but is definitely vulnerable to extreme storm events. This indicates a lack of robustness in the system.

Figure 3. Drainage Channel in Northwest Colorado Springs
Courtesy City of Colorado Springs

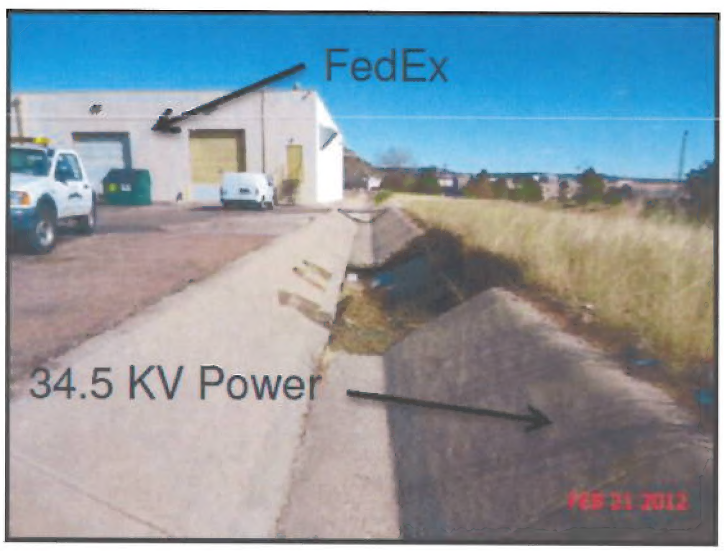

Figure 4. Same Channel Four Months Later
Courtesy City of Colorado Springs

Redundancy is not a typical characteristic of most stormwater systems, and Colorado Springs's stormwater system is no exception. It is theoretically possible to achieve redundancy by providing regional detention facilities as a backup for local or on-site detention facilities, for example. This, however, is normally not done due to economic realities. Furthermore, alternate drainage ways are not a part of the Colorado Springs system. When the stormwater demand exceeds the capacity of a system component the result is generally flood damage and/or loss of use of adjacent infrastructure components, such as bridges or roads. Given the economic realities of stormwater system design and construction, redundancy cannot generally be considered a practical way to improve stormwater system resilience.

It is the Advisor's opinion, having observed local governance over the last 30 years, that Colorado Springs's stormwater system resilience is enhanced by local resourcefulness. To illustrate by way of contrast, there have been allegations of bureaucratic ineptitude contributing to the Katrina disaster in 2005. Without attempting to make a judgment regarding that controversy, there is no question that a nimble, resourceful municipal government contributes to the resilience of that jurisdiction's infrastructure systems. Discounting the periodic squabbles and accusations that seem inevitable in local politics, the Colorado Springs elected officials and city staff members have been creative and responsive when faced with stormwater-related challenges. There is a "can do" attitude and willingness to work with adjacent jurisdictions and communities that contributes to maintaining a largely effective stormwater system despite the challenges of operating in an environment of significantly constrained resources.

Figure 5. Drainage Channel in Colorado Springs
Courtesy City of Colorado Springs

As noted previously, rapidity is closely linked to resourcefulness when assessing the resilience of an infrastructure system. Furthermore, both resiliency and rapidity depend on available resources to a significant degree. Unfortunately, while resourcefulness can be considered a strength of Colorado Springs's stormwater infrastructure system, the ability to rapidly repair damaged stormwater system components is hindered by a decided lack of resources. Historically the City has wrestled with the best way to provide adequate funding for stormwater capital improvement projects as well as maintenance support. In 2005, the City Council voted to establish the Stormwater Enterprise (SWENT) for the purpose of overseeing the City's stormwater infrastructure system. As part of the SWENT initiative, the City also authorized a fee collection vehicle to provide funding for stormwater capital projects. In 2009, responsibility for funding stormwater system maintenance projects was also turned over to SWENT, but no funding increase accompanied this additional mandate. SWENT fees collected from 2007 to 2009 totaled approximately $43 million, and SWENT spent $21 million on stormwater capital improvement projects and $13 million on stormwater maintenance projects from 2007 to 2010. However, at the end of 2009, the City Council reversed course and voted to phase out SWENT and eliminate the collection of SWENT fees. During SWENT's existence, progress was made in reducing the stormwater system project backlog, but the current estimate for the stormwater system backlog is approaching $500 million. Without a consistent method of funding stormwater maintenance and capital projects it stands to reason that the ability to rapidly respond to storm events and repair damaged stormwater system components is significantly impaired. This, in turn, has reduced the resilience of the Colorado Springs stormwater infrastructure system. Unfortunately, a decrease in resilience generally doesn't manifest itself until an extreme event occurs. If a 1999-type flood doesn't occur for another 20 to 30 years the chances are good that the general public will assume that all is well with the stormwater system. And in a sense, they will be correct. But who can measure the additional costs and possibly even lives that could have been saved when that next violent episode does occur had only the community maintained a reasonable, consistent investment program in the stormwater system over the years?

SUMMARY AND CONCLUSIONS

The ASCE Infrastructure Report Card evaluation procedure grades the capacity, condition, funding, future need, operations and maintenance, public safety and resilience of each infrastructure category. These separate grades are combined using a weighting process to arrive at a single final grade for each infrastructure category, such as stormwater. The ASCE Colorado Springs Infrastructure Report Card assessment process is in progress at this writing and won't be publically released until the summer of 2012. Part of the Report Card process is to submit the report to a third party for independent review. Since this has not yet taken place, no final rating for the stormwater system resilience will be provided at this time.

However, based on the discussion contained herein, certain conclusions can be drawn regarding Colorado Springs's stormwater infrastructure resilience. The system preforms adequately under normal conditions, but is distinctly vulnerable to extreme events. By definition, it is not a robust system. As is typical of most stormwater systems, it does not have built-in redundancy. The resourcefulness of those responsible for the stormwater infrastructure in Colorado Springs is a positive contributor to the system resilience, but the absence of a consistent funding mechanism

significantly reduces the ability to rapidly respond to severe events and quickly repair resulting damage. As a result of these factors, the Colorado Springs stormwater system is lacking resilience. This lack of resilience is a latent vulnerability that will only become widely evident when the next extreme storm event occurs.

REFERENCES

(1) David Eng and Stanley Rader, "Blazing a Trail: Initial Infrastructure Protection Education at the U.S. Air Force Academy", *The Homeland Security Review*, Volume 5, No. 3, California University of Pennsylvania, Fall 2011, pp. 259 – 279

(2) *ASCE State & Regional Report Cards; A Guide to Grading Your Community's Infrastructure*, American Society of Civil Engineers, p. 18

(3) "2009 Report Card for America's Infrastructure", American Society of Civil Engineers, 2009, pp. iv – v

(4) Scott Jackson, "The Principles of Infrastructure Resilience" , DomesticPreparedness.com, February 17, 2010

(5) Michel Bruneau and Andrei Reinhorn, "Exploring the Concept of Seismic Resilience for Acute Care Facilities", *Earthquake Spectra*, Volume 23, No. 1, Earthquake Engineering Research Institute, February 2007, pp. 41–62

(6) "Regional Disaster Resilience; A Guide for Developing an Action Plan, 2011 Edition", The Infrastructure Security Partnership, 2011

(7) Paul Mlakar, National Report Card Presentation, American Society of Civil Engineers, 2008

(8) Paul Mlakar, National Report Card Presentation, American Society of Civil Engineers, 2008

(9) "Regional Disaster Resilience; A Guide for Developing an Action Plan, 2011 Edition", The Infrastructure Security Partnership, 2011, pp. 52-53

(10) National Center for Atmospheric Research, "Climate Variability and Uncertainty in Flood Hazard Planning in Colorado," http://www.assessment.ucar.edu/flood/flood_table.html, 2004